

Precision Apiculture: Continuous Beehive Monitoring

Bio-Geo Spatial Technologies Seminar

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October 23rd

Presentation Overview

- Background:
 - Pollination & Precision Apiculture
- Beehive Sensor Network
 - Hardware
 - Software
- Effects of Electromagnetic Radiation on Beehive Health
 - Results of 2015 Field Season
- Conclusions and Outlook on Hive Sensors

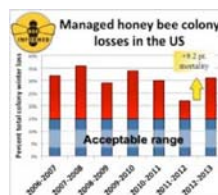
Pollination: Angiosperm Plant Reproduction

- Pollen: Gamete cells
- Enables fertilization, reproduction, and fruiting
- 200,000 species of animal pollinators
- 1 in 3 bites of food derived from pollination by honeybees
- Global honeybee pollination in 2005 valued at \$200 billion.



Colony Collapse Disorder

- Characterized by a disappearance of worker bees inside the hive
- Translates to \$15 billion of lost crops in the U.S.A.



Province	Number of Colonies Wintered Fall 2013	Number of Dead or Unproductive Colonies Spring 2014*	Percent Wintering Loss (%)
British Columbia	39,047	5,858	15.0
Alberta	282,000	52,170	18.5
Saskatchewan	100,000	18,800	18.9
Manitoba	71,000	17,040	24.0
Ontario	100,000	58,010	58.0
Quebec	50,000	9,000	18.0
New Brunswick	10,252	2,700	26.3
Nova Scotia	18,500	4,200	22.7
Prince Edward Island	6,995	1,338	19.1
Newfoundland and Labrador		Data Not Available	
CANADA	677824	109,196	25.0**

Precision Apiculture:

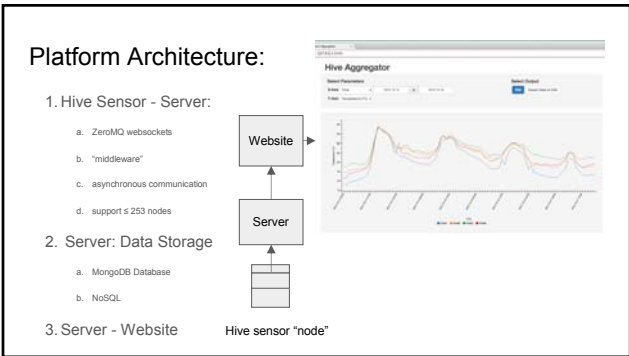
- Beehive data difficult to collect:
 - Little quantitative data exists on hive conditions and observations from hive inspections are not often integrated into research (Mezquida and Martinez, 2009)
- Results in methodological shortcomings:
 - In Colony Collapse Disorder (CDD) research, hives are sampled only after an incident is reported (USDA 2008).
- Solution: In-hive sensor systems

Precision Apiculture

- Definition:
 - "Precision Beekeeping (PB), a sub-branch of Precision Agriculture, is an apiculture management strategy based on the monitoring of individual bee colonies to minimise resource consumption and maximise the productivity of bees." (Zaccapines et al, 2015)
- Main parameters tested:
 - Climatic (temperature, humidity, air pressure)
 - Hive weight
 - Acoustics
 - Gas concentrations

Table 9. Summary of research using continuous monitoring methods.

Parameter	Method	Location	No. of replicates	Duration of hourly datasets	Reference
Weight and temperature	Mechanical balance and in-bee activity thermocouples	Field	1	1 year, hourly dating	Giles (1914)
Weight	Mechanical balance	Field	2	60 days	Haackstone (1927)
Weight	Electronic balance	Field	1	6 months	Wachmann and Thoenen (1998)
Weight	Electronic balance	Field	2-4	10 months	Muller et al. (2010, 2005)
Temperature	Electric thermocouples	Insulated room	1	8 months, hourly dating for 40 days	Phillips and Dethleff (1914)
Temperature, [CO ₂ and [O ₂]	Electric thermocouples, methanolic chamber with ventilated air passed through external detector	Field	1	3 days	Milner (1921)
Temperature	Forced air passed over thermometer	Field	1	Approx. 7 days	Swadlow and Magoon (1971)
Temperature, [CO ₂ , and [O ₂] in of beehive house	In-bee activity thermocouples, external air passed through external detector	Not stated	1	32 h	Serdy (1974)
Temperature, [O ₂ in of beehive house	Methanolic chamber with ventilated air passed through external detector	Laboratory	Not stated	Series of 24-48 h experiments over 14 months	Koenig and Miller (1952)
Temperature, [CO ₂ and [O ₂]	Forced air passed through detector	Field	10	Not specified, some periods of at least 12 h	Swadlow and Miller (1967)
Temperature, [CO ₂ and [O ₂], humidity	In-bee temperature sensors, external air passed through external detector	Field and laboratory	Not stated	10 weeks	Van Steen and Buelow (1997)
Temperature	In-bee sensors	Field	8	2 weeks	Stiles et al. (2004)
Temperature, humidity	In-bee sensors	Field	3 (incl. single colony)	4 days	Blumen et al. (2008)
Temperature	In-bee sensors	Field	14	1 year	Schulz and Bernisse (2012)
Vibration	In-bee sensors	Field	2	Approx. 9 months	Bonville et al. (2011)
Acoustics, temperature, relative humidity	In-bee sensors	Field	3	276 h	Farnet et al. (2009)
Acoustics, temperature	In-bee sensors	Field	10	Approx. 1 year	Ahmed Mousalala and Christian Mader (2005)
Finger traffic	Video entrance sensor	Field	1	23 days	Brandl and Dettl (1981)
Finger traffic	Video entrance sensor	Field	40	9 days	Dunka and Ruster (2007)
Finger traffic	RFID tags and entrance	Field	2	10 trials of up to 10 days	Schneider et al. (2012)



Continuous Beehive Monitoring Hardware

Sensor Components: ~\$100

- Raspberry Pi (microcontroller)
- DHT22 Temperature and Humidity Sensor
- PLMC15 Omnidirectional Microphone

Server: Intel Atom D525 / Thinkpad t530

-Linux Debian OS

Software & Demonstration

- 2 pieces of software run simultaneously:
 - Server software
 - continuously "listening" for hive sensors
 - Hive sensor software
 - continuously sampling DHT22 sensor and microphone and sending to server
- Server software: "hive-aggregator.py"
- Hive-sensor software: "hive-node.py"

Audio Signal Processing:

- From a 3 second audio recording
- Amplitude calculation (dB):
 - Fast Fourier transform
 - $dBm = 20 \cdot \log(\text{amplitude})$
- Dominant frequency calculation:
 - Fast Fourier transform
 - Create histogram of frequency distribution
 - take median

Fourier Transform animation

Research Objectives: Effects of Electromagnetic Radiation (Wi-Fi 2.4GHz) on Beehives

A Precautionary Study:

- Wireless sensor network useful in precision apiculture

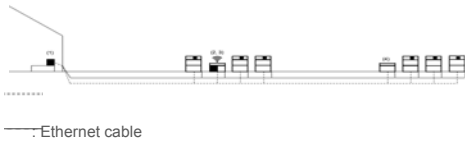
Effects of EMR on animals: Varying results

- Interferes with navigation in migratory robins
 - Magnetite Fe₃O₄ is used in magnetoreception in robins and honeybees
- Reproduction, spatial memory in insects
- "Electromagnetic Hypersensitivity" in humans

2.4Ghz Justification: no research exists on its effects on honeybees, it is used in

Experimental Methods:

- 2.4GHz (Wi-Fi) exposed to treatment hives (n=3) for 72 hour periods during September and October, 2015.
- Varroa sample
- Honey frame photo analysis



Wi-Fi Intensity Maps

- Device: RF Spectrum Analyzer
- n > 300



Fig 1. 2: Map of apiary without Wi-Fi Signal (left), and with (right).

Results: Climate Data

	External Climate Correlation r^2	
	Temperature	Humidity
Control Hives	0.86	0.09
Treatment Hives	0.77	0.09

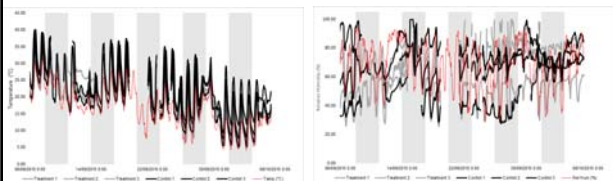
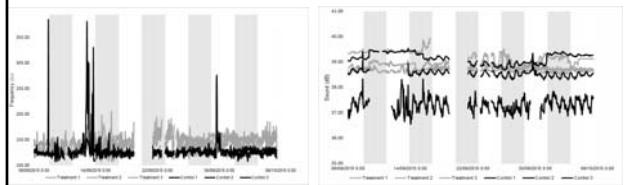


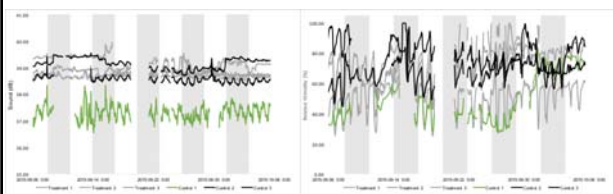
Fig 1. 3: Hourly averages of experimental data. Gray shaded areas represent 2.4GHz exposure. External temperature and humidity data are represented in red and from the Trudeau Weather Station, Dorval, QC.

Results: Acoustic Data



Figures 3. 4: Hourly averages of experimental data. Gray shaded areas represent 2.4GHz exposure.

Outlier: Control Hive 1



Varroa destructor. Honeybee parasite

- Varroa mite

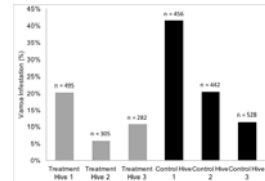


Fig 1. Per hive Varroa destructor infestation rate, honeybee sample size reported on graph.

Honey Frame Photo Analysis

- Honey supers extracted from all hives July 25th
- Track rate of honey production



Fig 1. Measuring pixel area using ImageJ

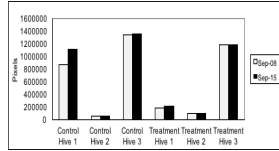


Fig 2. Frame photo analysis of 3honey super, area of capped honey in pixels.

Measuring effect of EMR: Data analysis

Normalization formula:

$$Diff_{n,m} = [Tr_{n,i}(on) - Tr_{n,i}(off)] - [Cr_{m,i}(on) - Cr_{m,i}(off)]$$

where $Diff_{n,m}$ is the difference between nth treatment and mth control for the ith record; $Tr_{n,i}$ is the measured parameter for the nth treatment and ith record; $Cr_{m,i}$ is the average measured parameter for the nth treatment when Wi-Fi was off;

$$Tr_{n,i}(on) = \frac{Tr_{n,i}(on) + Tr_{n,i}(off)}{2}$$

Data analysis results: Sound

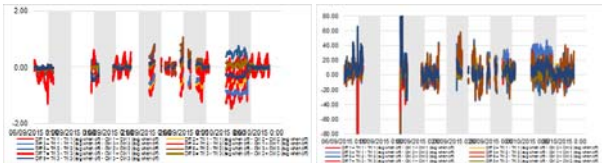


Fig 1, 2. Normalized graphs of frequency data(left) and amplitude (right). Data containing outlier hive (Control 1) highlighted in red

Data Analysis Results: Climatic Conditions

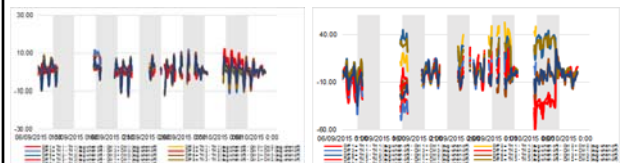


Fig 1, 2. Normalized graphs of temperature (left) and humidity (right). Data containing Varroa infested hive (Control 1) highlighted in red

Results

	Temp (C)		Humid (%)		Sound (dB)		Sound (Hz)			Temp		Humid		Sound (dB)		Sound (Hz)	
	St.dev	Mean	St.dev	Mean	St.dev	Mean	St.dev	Mean		St.dev	Mean	St.dev	Mean	St.dev	Mean	St.dev	Mean
DHF 1	3.95	1.90	18.37	19.80	21.43	-6.65	21.43	18.82	DHF 1	2.29	0.00	7.66	0.00	6.46	0.00	6.46	0.00
DHF 2	4.35	2.10	20.95	15.09	0.27	-0.33	15.04	11.44	DHF 2	3.51	0.00	7.74	0.00	0.09	0.00	6.48	0.00
DHF 3	4.50	2.87	17.01	-11.83	0.15	-0.46	16.36	20.39	DHF 3	3.90	0.00	7.94	0.00	0.07	0.00	7.50	0.00
DHF 4	3.16	1.85	15.42	-14.88	0.34	-0.07	20.98	0.17	DHF 4	2.31	0.00	6.45	0.00	0.23	0.00	13.75	0.00
DHF 5	3.96	1.04	14.76	21.82	0.29	0.25	20.71	-0.41	DHF 5	3.89	0.00	6.21	0.00	0.11	0.00	14.06	0.00
DHF 6	4.13	1.91	8.28	-7.47	0.29	0.25	20.71	-0.41	DHF 6	4.27	0.00	7.66	0.00	0.11	0.00	14.06	0.00
DHF 7	4.13	1.05	15.25	-15.78	0.23	-0.30	11.84	3.90	DHF 7	4.27	0.00	4.83	0.00	0.20	0.00	5.67	0.00
DHF 8	3.45	0.85	13.83	20.92	0.07	0.03	8.94	3.32	DHF 8	3.53	0.00	5.04	0.00	0.06	0.00	6.22	0.00
DHF 9	3.71	1.78	8.42	-8.37	0.23	-0.11	14.93	10.25	DHF 9	3.83	0.00	6.56	0.00	0.04	0.00	6.77	0.00

Table 1, 2. Means and Standard Deviations of Normalized values when Wi-Fi is on (right) and off (left)

Discussion

- Not able to detect any effect from 2.4GHz
 - No effect measured in this study ≠ Wi-Fi is completely safe to use
 - Precautionary principle
 - Small sample size
 - Long term and/or delayed effects of exposure
- High Varroa infestation noticed in sensor data
 - Consistent with literature
- Honeybees generate humidity, temperature parallels with external fluctuations

Conclusion:

- Continuous in-hive monitoring produces rich datasets
- Sensor network proven research tool
 - Precision apiculture research largely exploratory
- Next steps: distilling key parameters
 - Determining best in-hive location(s) for sensors
 - Other parameters and technologies
 - infrared
 - Tension between apicultural research and management interests

Thanks! Questions?



Remote Sensing Data Based Crop Growth Parameters Retrieval and Crop Management Zone Delineation Research


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McGill University, Canada

Contents


- General Introduction
- Crop Plant Zone Extraction
- Crop Growth Parameters Retrieval
- Crop Management Zone Delineation

Research Background

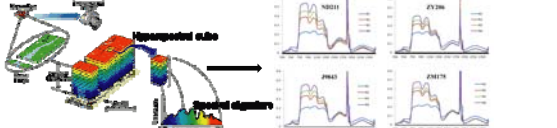
Practical needs: crop growth and its spatial variation information



Point scale



Regional scale



Hyperspectral data: contiguous spectrum

Contents

- General Introduction
- Crop Plant Zone Extraction
- Crop Growth Parameters Retrieval
- Crop Management Zone Delineation

Crop plant zone extraction based on HSI

Problem to solve

- **Curse of dimensionality**
 - ✓ Less training samples
 - ✓ Poor generalization
- **Dimensionality reduction**
 - ✓ Band selection
 - ✓ Feature extraction

Band selection based on scatter matrices

■ **Scatter Matrices**

- ✓ Within-class distance, inter-class distance
- ✓ No normal distribution restriction
- ✓ Extend from two classes to multi-classes

$$SB_{ij} = P_i(\mu_i - \mu_0)(\mu_i - \mu_0)^T + P_j(\mu_j - \mu_0)(\mu_j - \mu_0)^T$$

$$SW_{ij} = P_i\Sigma_i + P_j\Sigma_j$$

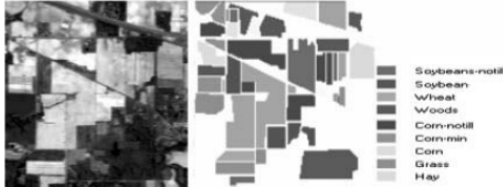
$$S_{ij} = \text{trace}\{SW_{ij}^{-1}SB_{ij}\}$$

$$S_{ave} = \sum_{i=1}^M \sum_{j>i}^M P_i P_j S_{ij}$$

Band selection based on scatter matrices

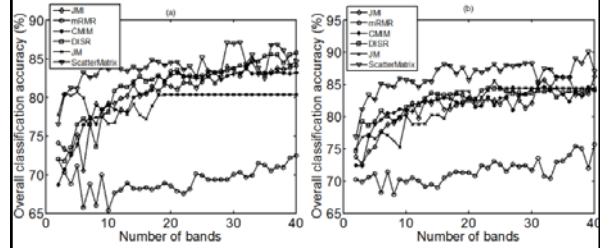
■ AVIRIS hyperspectral image

- ✓ Band number 200; spatial resolution 20m
- ✓ Agricultural area in the north of Indiana, America
- ✓ Corn, soybean, wheat, forest and grassland



Band selection based on scatter matrices

■ Experimental results



Band selection based on scatter matrices

■ Experimental results

Method	Num. of bands	OA	KC	PA				
				Class 1	Class 2	Class 3	Class 4	Class 5
JMI	40	0.863	0.798	0.823	0.861	0.982	0.913	0.839
mRMR	40	0.757	0.644	0.708	0.732	0.945	0.883	0.623
CMIM	32	0.846	0.773	0.784	0.844	0.982	0.917	0.839
DISR	23	0.844	0.768	0.760	0.852	0.982	0.938	0.750
JM	24	0.856	0.788	0.843	0.843	1.000	0.899	0.818
ScatterMatrix	39	0.901	0.853	0.891	0.885	1.000	0.948	0.856

A hybrid feature extraction method

■ PCA + ScatterMatrix

- ✓ PCA: unsupervised feature extraction method
- ✓ No guarantee to good class separability

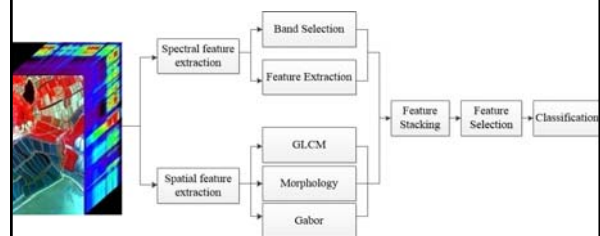
A hybrid feature extraction method

■ Experimental results

Method	Num. of features	OA	KC	PA				
				Class1	Class2	Class3	Class4	Class5
PCA	6	0.840	0.764	0.807	0.824	0.982	0.932	0.712
ICA	15	0.827	0.746	0.822	0.822	1.000	0.843	0.792
PCA_ScatterMatrix	13	0.865	0.799	0.820	0.878	0.982	0.909	0.746
LDA	4	0.824	0.743	0.815	0.784	0.982	0.905	0.856
NWFE	7	0.892	0.840	0.873	0.908	1.000	0.891	0.818

Fusion of spectral and spatial features

■ Multi-feature fusion



Contents

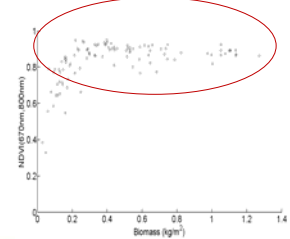
- General Introduction
- Crop Plant Zone Extraction
- Crop Growth Parameters Retrieval
- Crop Management Zone Delineation

Remote sensing data based crop growth parameter retrieval

■ Crop growth parameters

- ✓ LAI
- ✓ Biomass
- ✓ Nitrogen concentration

■ Saturation problem



LAI VI sensitivity analyses based on PROSAIL model

■ Sensitivity function

- ✓ Saturation ,LAI >=3
- ✓ R² and RMSE
- ✓ Sensitivity changes according to LAI value

$$s = \frac{SVI'}{\sigma_{SVI}} = \frac{d(SVI)/d(LAI)}{\sigma_{SVI}}$$

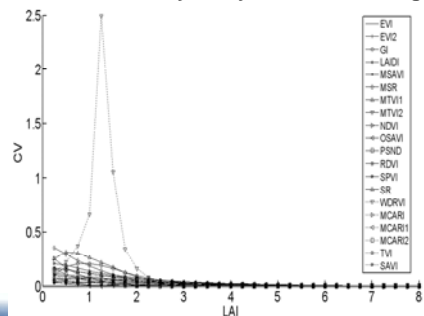
LAI VI sensitivity analyses based on PROSAIL model

■ Sensitivity analyses

- ✓ Simulated canopy spectral datasets based on PROSAIL
- ✓ Common-used VIs
- ✓ Sensitivity to soil background
- ✓ Sensitivity to leaf chlorophyll
- ✓ Anti-saturation analyses

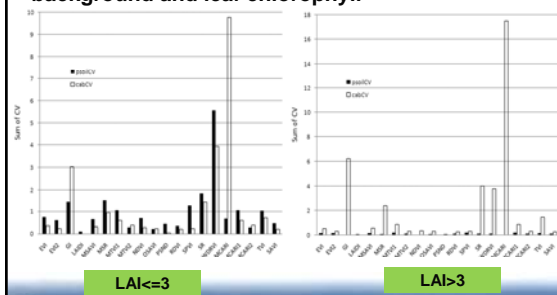
LAI VI sensitivity analyses based on PROSAIL model

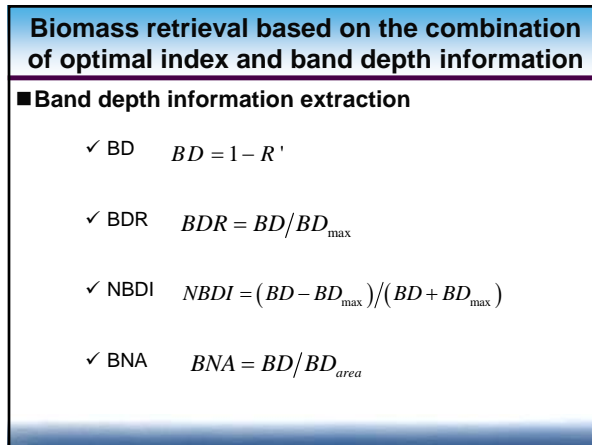
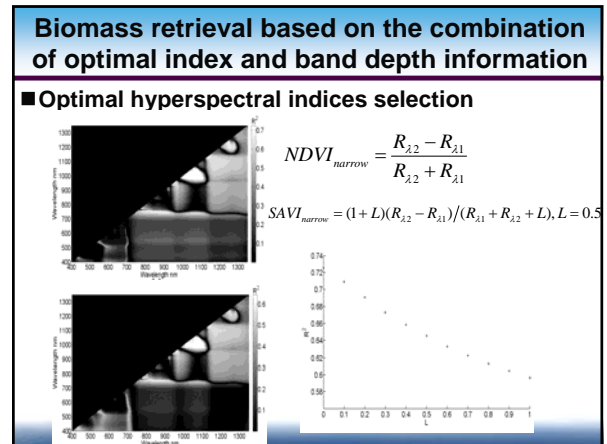
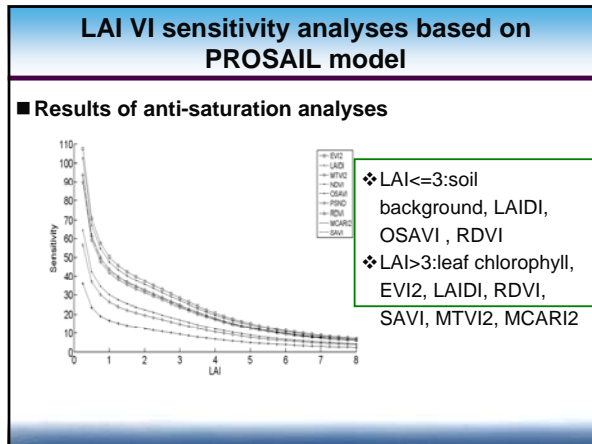
■ Results of VI sensitivity analyses to soil background



LAI VI sensitivity analyses based on PROSAIL model

■ Results of conjunction sensitivity analyses to soil background and leaf chlorophyll





Biomass retrieval based on the combination of optimal index and band depth information

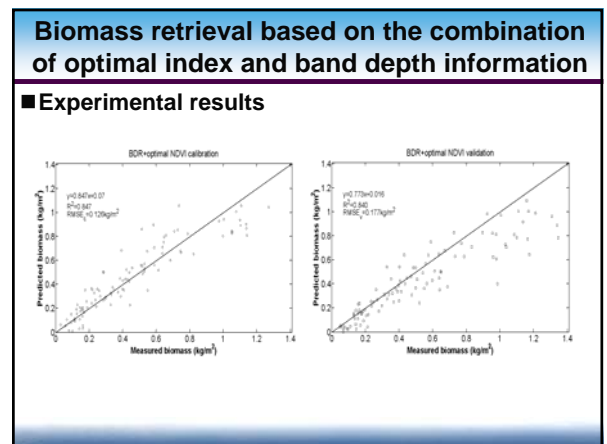
■ Experimental results

Spectral predictors	Calibration		Independent validation	
	R ²	RMSE _c (kg/m ²)	R ²	RMSE _v (kg/m ²)
Narrow band indices				
NDVI(800nm and 670nm)	0.210	0.285	0.165	0.344
SAVI(800nm and 670nm)	0.117	0.302	0.046	0.366
Optimal NDVI-like(1097nm and 980nm)	0.726	0.168	0.760	0.279
Optimal SAVI-like(1084nm and 1026nm)	0.645	0.191	0.711	0.289
Red edge position(REP)				
Maximum first derivative	0.496	0.228	0.240	0.333
Linear interpolation	0.567	0.211	0.193	0.350
Inverted Gaussian model	0.571	0.210	0.221	0.341

Biomass retrieval based on the combination of optimal index and band depth information

■ Experimental results

Method	No. of factors	Calibration		Independent validation	
		R ²	RMSE _c (kg/m ²)	R ²	RMSE _v (kg/m ²)
BD	4	0.792	0.146	0.696	0.211
BDR	5	0.830	0.132	0.735	0.193
NBDI	4	0.781	0.150	0.622	0.233
BNA	4	0.783	0.149	0.687	0.211



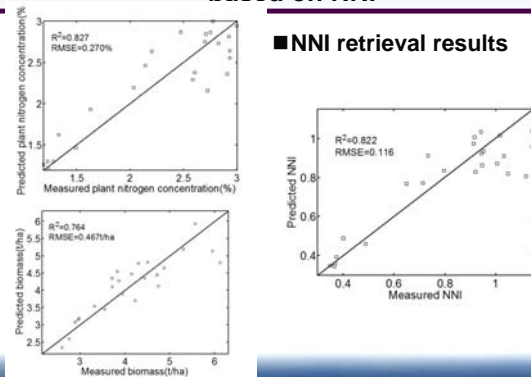
NNI Retrieval and wheat GPC estimation based on NNI

■ Canopy spectrum->NNI->wheat GPC

- ✓ No direct relationship between spectrum and GPC
- ✓ Relationship between nitrogen concentration and GPC
- ✓ NNI: ratio of plant nitrogen concentration and critical plant nitrogen concentration
- ✓ NNI retrieval: the retrieval of plant nitrogen concentration and above ground biomass

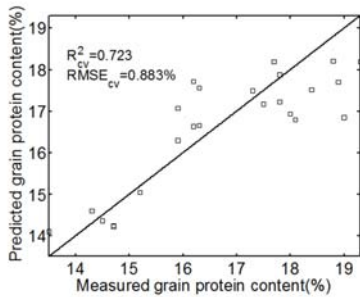
NNI Retrieval and wheat GPC estimation based on NNI

■ NNI retrieval results



NNI Retrieval and wheat GPC estimation based on NNI

■ GPC estimation results



Crop growth parameters retrieval and monitoring based on CASI HSI

■ Study area and datasets

- ✓ Heihe basin in China
- ✓ CASI HIS: band number 48, spatial resolution 1m
- ✓ LAI samples: corn (11), vegetables (3)

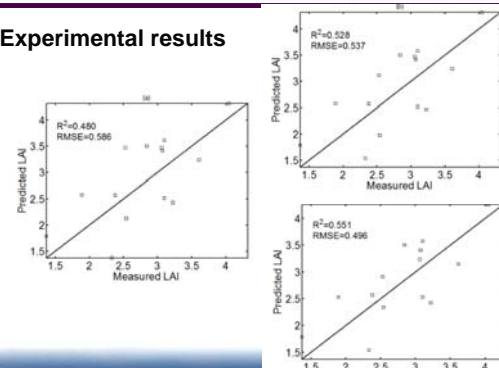
LAI VI sensitivity analyses based on PROSAIL model

■ Lookup table based LAI retrieval

- ✓ Simulated canopy spectral datasets based on PROSAIL
- ✓ Look up table : easy to realize, more stable
- ✓ Average of multi-solutions: ill-posed problem

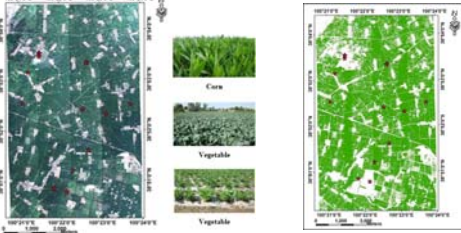
LAI VI sensitivity analyses based on PROSAIL model

■ Experimental results



LAI VI sensitivity analyses based on PROSAIL model

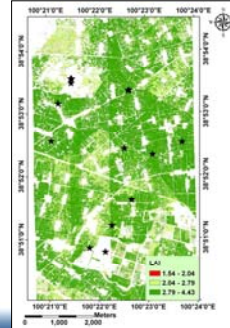
■ Crop plant zone extraction



- ❖ Non-vegetation region removal: NDVI threshold
- ❖ Band selection: 483nm, 554nm and 726nm, SVM

LAI VI sensitivity analyses based on PROSAIL model

■ LAI distribution map



Thanks!